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CALIBRATION OF PATS AT DREA CALIBRATION BARGE

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GUIGNE INTERNATIONAL Ltd.

DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

Contractor Report

DREA CR 1999-080

April 1999

Défense nationale National Defence

Canada

102-02917/

National Defence
Research and Development Branch

Défense nationale
Bureau de recherche et développement

DREA CR 1999/080

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W7707-8-6319A
Contract Number

April 1999

CONTRACTOR REPORT

Prepared for

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

Canada

ABSTRACT

This report describes the calibration of the PATS sonar during January 1999 at the DREA Calibration Barge. The PATS sonar is a high-powered low-frequency parametric array designed and built by Guigné International Ltd., Paradise, Newfoundland. Tests were carried out at the primary frequency of 100 kHz and difference frequencies 1, 2, 4, 8 and 10 kHz. Measurements were carried out at ranges between 3 m and 16 m from the transducer face along the acoustic axis. At a range of 10 m beam pattern measurements at difference frequencies 2, 4 and 8 kHz were made. Measurements in both the time and frequency domain, over the frequency range 90 to 510 kHz, were made which illustrate the harmonic distortion brought on by finite amplitude propagation of a 100 kHz CW signal. This report describes the experimental setup, methodology, data format, data organization, and graphically presents a portion of the data collected. A comprehensive theoretical evaluation of the data was not performed. This work was carried out with the assistance of the Scientific Authority, and DREA technical staff, and was supported by DSS Contract W7707-8-6319/A.

RÉSUMÉ

Ce résumé décrit l'étalonnage du sonar PATS en janvier 1999 à la barge d'étalonnage du CRDA. Le sonar PATS est un réseau paramétrique sonar basse fréquence de grande puissance conçu et construit par Guigne International Ltd., Paradise, Terre-Neuve. Des essais ont été réalisés à la fréquence primaire 100 kHz et aux fréquences différentielles 1, 2, 4, 8 et 10 kHz. Des mesures ont été prises à des portées de 3 m et de 16 m du transducteur, face à l'axe acoustique sur sa longueur. À une portée de 10 m, on a pris des mesures du diagramme de faisceau aux fréquences différentielles 2, 4 et 8 kHz. On a pris des mesures dans le domaine temporel et le domaine de fréquences pour l'intervalle de fréquences de 90 à 510 kHz, en vue d'illustrer la distorsion harmonique causée par la propagation d'amplitude finie d'un signal en ondes entretenues de 100 kHz. Le rapport décrit le montage expérimental, la méthodologie, le format et l'organisation des données et comporte des représentations graphiques d'une partie des données recueillies. Aucune évaluation théorique globale des données n'a été effectuée. Les travaux ont été réalisés avec l'aide de l'autorité scientifique et le personnel technique du CRDA et ont été appuyés par le contrat du MAS W7707-8-6319/A.

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1.0 INTRODUCTION

Guigné International Limited has built a high-power, low-frequency parametric array, PATS (Parametric Array Transmit System). PATS was commissioned by the Defence Research Establishment Atlantic to be the acoustic transmitter on DREA's wideband sonar. That system is described elsewhere [1]. The parametric array was designed to operate across a difference frequency band of 1 kHz to 10 kHz using a primary center frequency of 100 kHz. The maximum primary source level of the array was designed to reach 242 dB re 1μPa@1m.

1.1 Background

The first acoustic calibration of PATS took place in January-February of 1998 in St. John's, Newfoundland, in the Institute for Marine Dynamics (IMD) deep tow tank. The IMD facility is described elsewhere [2]. A detailed description of the first calibration exercise was reported previously [3]. After the first calibration exercise a problem with the linearity of the amplifiers was discovered. This problem severely affected acoustic performance. During the period March to December 1998 this problem was rectified, and the sonar was readied for shipment to Halifax for testing in January of 1999.

1.2 Purpose of Report

In this report we describe the second calibration exercise of PATS at the DREA Barge Facility, located on Bedford Basin, Halifax, and show representative data collected during that exercise. The Barge calibration took place between January 25 and 29, inclusive. Cataloging and preliminary processing of the data took place during the week February 1 to 5, inclusive, at the DREA lab. A detailed comparison of the data to theoretical predictions is not presented in this report, as this analysis will be completed by the Scientific Authority at a later date.

2.0 MEASUREMENTS

The DREA Barge is an enclosed work space and provides access to Bedford Basin through a 9 m by 18 m rectangular well. Transducers can be moved anywhere within this well, and can be mounted and rotated at depths from 2 to 40 m. With the exception of surface reflections, which can be minimize by lowering the transmitting and receiving apparatus, the facility provides a nearly free-field environment which makes it an ideal facility at lower frequencies. A more detailed description of the DREA Barge is found in reference [4].

For the calibration measurements the PATS head and hydrophone were held at approximately 5.33 m (17.5 ft.) depth. The measured temperature was 2.44 °C (26.4 °F), and the salinity was assumed to be 34 ppt. Using these figures the predicted sound speed was 1458.8 m/s [5]. This calculated sound speed was found to adequately predict propagation times between source and receiver.

2.1 Equipment

The signal generation and data recording setup is illustrated in Figure 1 of the appendix. The primary measuring instrument was the HP (Hewlett Packard) Vector Signal Analyzer (Model 89410A), usually referred to as the 'spectrum analyzer.' The HP 33120A arbitrary waveform generator and HP 3314A signal generator worked in concert to create the unamplified transmitted waveform. A BK Precision 3011B function generator acted as a trigger source for amplifier enable. A HP 54600A digital oscilloscope was employed as a monitor and for recording waveforms when required. The digital oscilloscope was connected via serial cable to a laptop computer for archiving of time series data via HP supplied Benchlink™ software. The digital oscilloscope had 8 bit resolution, limiting its dynamic range to 48 dB. This dynamic range is inadequate to simultaneously resolve the primary and secondary components of the transmitted waveform since, at best, these components are 40 dB apart. Therefore, the oscilloscope was employed to observe and record only the primary component at 100 kHz and higher frequencies.

A Reson TC4034 hydrophone was used as the acoustic receiver. The hydrophone bandwidth was sufficient to receive both primary frequencies between 95 to 105 kHz and the difference frequencies below 10 kHz. The hydrophone sensitivity in the difference frequency band was -216.4 dB re 1V/μPa. The hydrophone sensitivity in the primary frequency band was -217.2 dB re 1V/μPa. In order to take measurements at 16 m range, additional cable was attached to the hydrophone cable. To account for this added cable, 4.7 dB were added to those measurements.

Transmitted signal amplitude was adjusted on the HP3314A function generator. This instrument displays the unamplified signal level in an LCD display. The value in that display was referred to as the "Level' during the calibration.

2.2 Beam Patterns

Beam patterns were measured prior to axial, or range, measurements. This enabled confirmation of proper alignment with the maximum response axis, MRA (or acoustic axis), before proceeding to measurements on axis. If a beam pattern was not recorded prior to an on-axis measurement, it was the norm to perform a quick exercise that ensured alignment with the MRA. This was done by moving the hydrophone, and/or rotating the PATS transmit head, such that the signal maximum was located.

Beam pattern measurements were taken at a range of 10 m, at difference frequencies 2 kHz, 4 kHz, and 8 kHz. All beam patterns, regardless of difference frequency, were measured with a power corresponding to the 600 mV "Level" on the HP 3314A generator.

2.3 Axial Measurements

Axial measurements were taken at ranges of 3, 4, 5, 6, 10 and 16 m from the PATS transmitter face. At each range the difference frequencies 1, 2, 4, 8 and 10 kHz were measured. For consistency all axial (MRA) measurements were taken with the "Level" set to 751 mV.

Extra measurements were made at 5 m range. At this range the RMS signal power supplied to the ceramics was ramped in 23 steps from 13 W to 1070 W (a range of approximately 20 dB) and the resulting sound pressure levels measured at 100 kHz and 4 kHz. This was repeated and the spectrum analyzer was set to view the harmonic content of a 100 kHz continuous wave signal in the frequency range 90 to 510 kHz.

3.0 DATA FILES

The following section describes the file types and software used to analyze and plot the results of the calibration. A description of the file name format is also included.

3.1 Programs Used

This section describes the programs that were used to read, convert, and display the collected data.

3.1.1 Hewlett Packard

The Hewlett Packard Vector Signal Analyser creates files with the extension "sdf" and writes these to a built-in diskette drive. The "sdf" files are highly compressed binary files (4 kilobytes) which contain all measurement header and signal data. Hewlett Packard supplies a set of software utilities with the instrument enabling the user to extract and convert the "sdf" data to a usable form. The utility used to convert sdf files into Matlab readable files was "sdf2ml.exe". This program was used by the Matlab source file called "showhpspec.m". In "showhpspec.m" the "sdf" file is opened via the DOS shell script:

sdftoml <file>.sdf <file>.mat /x /y:r

This DOS script extracts the frequency vector and linear RMS spectrum (rms_level) from the "sdf" file and saves the result to a Matlab binary "mat" file (7 to 10 kilobytes). To obtain dB re $1V_{RMS}$ in the spectrum, the linear RMS spectrum level is converted via:

dB re 1 V_{RMS} = 20*log10(abs(rms_level))

which was confirmed on site at the Barge. The frequency vector in the mat file has units of Hertz. The mat files are loaded by the Matlab command

load <file> (no extension is required as the default extension is "mat" on "load")

Also in "showhpspec.m", the HP utility, "sdftoasc.exe", was used to convert HP "sdf" files to get V_{rms} spectra in ascii data format. Using this utility "sdf" data were converted to ascii "txt" files (13 kilobytes). The "txt" file contains two columns of space delimited data. The first column is frequency in Hertz, and the second column is (linear units) volts rms. As in the conversion to "mat" files, the command

sdftoml <file>.sdf <file>.txt /x /y:r

was used to perform the conversion to ascii data.

Finally, the HP utility "sdfprint.exe", utilised in "showhpspec.m", extracted the header information from the "sdf" file. The header information contains all spectrum analyser instrument status remarks and instrument settings valid at the time the data were collected. The header information was written to an ascii text file with the file extension "hdr" (8 kilobytes). The command to perform this operation was

sdfprint <file>.sdf <file>.hdr /h

To obtain more information, about any of the HP utilities type, in DOS, "sdftoasc /?", for example. In the Matlab shell, type the same but preceded by an exclamation symbol "!", i.e. type "!sdftoasc /?" (these utilities must be in the Matlab path).

Table 1. Hewlett Packard Utilities and their output.

Utility	Flags	Input Type	Output Type
sdftoml.exe	/x /y:r	HP binary "sdf" file	Matlab Binary spectrum: "mat"
sdftoasc.exe	/x /y:r	HP binary "sdf" file	ASCII two column spectrum: "txt"
sdfprint.exe	/h	HP binary "sdf" file	ASCII header information: "hdr"
BenchLink™	N.A.	raw oscilloscope data	ASCII time series: "prn"

3.1.2 Matlab

The function of the Matlab file "showhpspec.m" has already been described. Other Matlab files were created which took handwritten data from the Barge worksheets and compiled it into beam patterns, and axial sound pressure level (*SPL*) plots as provided in this report. The output of these files is now given.

Table 2. Matlab Files and their Output

Matlab File	Output
bp0210.m	Beam Pattern at R=10 m, fd=2 kHz, Level = 600 mV (on HP3314A generator display)
bp0410.m	fd = 4 kHz; R=10 m; Level = 600 mV
bp0810.m	fd = 8 kHz; R=10 m; Level = 600 mV
pats_range_cal.m	SPL vs. Range for fd=1, 2, 4, ,8 and 10 kHz for R=3, 4, 5, 6, 10 and 16 metres, Level = 751 mV
ramp4k.m	Acoustic output at fd=4kHz vs. Electrical Input (Watts RMS) to Tx array. R=5m, Signal fd=4 kHz, τ =4ms, depth = 17.5 ft, Avg=16; Files: See rpi5dd.sdf to rpi5dz.sdf
rampcw.m	Acoustic output vs. Electrical Input R=5m, Signal = 100 kHz CW pulse, τ=4ms, depth = 17.5 ft Files: rpi5a.sdf to rpi5z.sdf, and rpi5aa.sdf, rpi5ab.sdf
showhpspec.m	See Section 3.1.1
viewsdf.m	Loads mat file versions of sdf files and displays them in Matlab.

3.2 File Nomenclature

Many files were created by both the digital oscilloscope for recording time series data, and by the vector signal analyser for spectral data. Both instruments were limited to 8 character filenames, as per the old DOS standard limitation. The following sections describe the file nomenclature.

3.2.1 'BP' Files

Basic Description:
Beam Pattern

Detailed Description:
bp[fd(kHz)] [R(m)] [letter id: a-z, aa, ab, ... , ba, bb, ... , ca, cb, ...] . sdf

Format:
bp[##] [##] [% or %%] . sdf where: # is a single digit, % is a single character

Example:
bp0410b.sdf

Explanation:
Beam pattern at R= 10 m, difference frequency (fd) = 4 kHz. The letter identification (letter id) in these files each correspond to a different measurement angle in the beam pattern. Beam pattern measurements began far off axis, typically -20 or -40 degrees from the maximum response axis, went through the axis, and then proceeded to the other side of the beam at angles of 20 to 40 degrees.

3.2.2 'DIST' Files

Basic Description:
Harmonic Distortion data (acoustic)

Detailed Description:
dist [R(m)] [letter id: a-z] . sdf

Format:
dist [# or ##] [% or %%] . sdf where: # is a single digit, % is a single character

Example:
dist06c.sdf

Explanation:
Harmonic distortion data (data from > 100 kHz). The "dist" file dist06c.sdf (and therefore dist06c.mat) is harmonic distortion data taken at R = 6 m, and the characters , such as a, b, or c, in the filename signify different frequency ranges measured.

3.2.3 'MRA' Files

Basic Description:
Maximum Response Axis

Detailed Description:
mra [R(m)] [fd(kHz)] [letter id: a, b, c] . sdf

Format:
mra [##] [##] [%] . sdf

Example:
mra1601b.sdf

Explanation:
Data collected on the maximum response axis of the projector at a range of 16 m, and a difference frequency of 1 kHz. The letter and the characters , such as a, b, or c, signify different frequency ranges measured. The letter's correspond to following list of frequency ranges. The reader is cautioned that these are only guidelines and many exceptions may exist.
a = 500 Hz to 110 kHz
b = 0 to 105 kHz, or 500 Hz to 510 kHz
c = 500 Hz to 510 kHz

3.2.4 'RPI' Files

Basic Description:
Ramped Power Input (increasing Source Level). This file series includes data from two basic sets: i) 100 kHz CW, ii) 4 kHz difference frequency data when the primary is modulated at 2 kHz. In the second set, data were recorded in two frequency ranges in order to capture both the difference frequency band and harmonic content above 100 kHz.

Type 1:

Detailed Description:
rpi [R(m)] [letter id: a-z, ab, ab, ac] . sdf

Format:
rpi [#] [% or %%] . sdf

Example:
rpi5a.sdf

Explanation:
For these files, the signal is 100 kHz CW (no modulation), at a range of 5 m. The letters go from *a* to *z*, then *aa*, *ab*, and *ac*, with power increasing as the letter value increases (i.e. *a* is low power, *z* is high power, and *ac* had the highest power).

Type 2:

Detailed Description:
rpi [R(m)] [d *or* h] [letter id: d-z] . sdf

Format:
rpi [#] [%] [%] . sdf

Example 1 (Difference frequency data):
rpi5dd.sdf

Explanation:
The range is 5 m. For these files, the signal is modulated at 2 kHz, giving a 4 kHz difference frequency. The *d* after the 5 indicates that the data spans the difference frequencies. The letters go from *d* to *z* for this file series, with power increasing as the letter value increases (i.e. *d* is lowest power, *z* is the highest power).

Example 2 (Harmonic data):
rpi5ha.sdf

Explanation:
The range is 5 m. For these files, the signal is modulated at 2 kHz, giving a 4 kHz difference frequency. The *h* after the 5 indicates that the data spans frequencies at and above the primary frequency, thus capturing the harmonic content. The letters range from *a* to *z* for this file series, with power increasing as the letter value increases (i.e. *a* is low power, *z* is the highest power).

3.2.5 'MR' Files

Basic Description:
Maximum Response Axis (as in 3.2.3 but the 'A' was dropped to accommodate double characters in the letter id).

Detailed Description:
mr10[fd(kHz)] [letter id: aa, ab] . sdf

Format:
mr10 [##] [%%] . sdf

Example:
mr1010aa.sdf (All data in this series of files were collected at 10 m range.)

Explanation:
Maximum response axis data taken at 10 m range, and a difference frequency of 10 kHz. The *aa* corresponds to measured frequency range 500 Hz to 110 kHz, and *ab* corresponds to measured frequency range 500 Hz to 510 kHz.

4.0 Results

All graphical results are presented in Appendix A.

4.1 Electrical

The final electrical calibration of PATS was not available at the time of the Barge calibration. In light of an updated electrical calibration, undertaken since the tasks described in this report, the two sets of data presented here may be considered preliminary at the time of the Barge tests. Figure 2 shows the intermodulation distortion as function of amplifier output to the transducer ceramics. The vertical axis measures, in decibels, the level at which the intermodulation products are below the level of the primary signal. Figure 3 shows the delivered power to the transducer versus the input voltage to the amplifier network. This is plotted for modulation frequencies of 500 Hz, 1 kHz, 2, kHz, and 4 kHz. The 4 kHz data are dropping off, compared to the other, due to an increase in phase angle of the complex impedance to approximately -42 degrees, compared to less than 25 degrees for below 4 kHz (not shown).

4.2 Beam Patterns

As the primary frequency beam patterns were measured previously, these measurements were not repeated at this calibration. The primary beam patterns are presented elsewhere [3]. Beam patterns at the difference frequencies, for the same input signal level and range of 10 m, are presented in Figures 4 through 6 in Appendix A.

Figure 4 shows the beam pattern at a difference frequency of 2 kHz. The beam exhibits fair symmetry about the maximum response axis (zero degrees), and no sidelobes out to angles of 20 degrees. The -3 dB beamwidth was approximately 1.7 degrees.

Figure 5 shows the beam pattern at a difference frequency of 4 kHz. The beam exhibits fair symmetry about the maximum response axis, and no sidelobes out to angles of 45 degrees. The -3 dB beamwidth was approximately 2 degrees. Three symbol styles are shown in Figure 5. This is due to a problem encountered with the shaft encoder while taking data on the barge. In order to track the data different symbols were thus used. The figure shows the three data sets in reasonable alignment.

Figure 6 shows the beam pattern at a difference frequency of 8 kHz. The beam exhibits fair symmetry about the maximum response axis, and no sidelobes out to angles of 45 degrees (on the left). The -3 dB beamwidth was approximately 1.3 degrees.

4.3 Axial Measurements

In this section, we present measurements obtained on the acoustic axis of the transmitter. The measurements include data collected at fixed ranges where the output power was increased, and the resulting acoustic output observed. As well, data were collected where the range was changed while the output power was fixed, but the modulation frequency changed.

4.3.1 CW Pulse Source Level

Figures 7 and 8 illustrate the acoustic output versus input power to the ceramics. The measured source level, *SL*, was determined by the equation,

$$SL = RL - OCV + 20\log_{10} R + \alpha_{dB} R \qquad dB \tag{1}$$

where *RL* is the dBV_{rms} spectrum level of the received signal as measured by the spectrum analyzer, *OCV* is the receiving response of the hydrophone, corrected for any associated extra cable, α_{dB} is the absorption loss, and *R* is the range of measurement from the transmitter. At 100 kHz, in seawater, *S*=35 ppt and α_{dB} = 0.03 dB/m. The solid line in Figure 7 was calculated using the expression for *SL* versus input power, P_{input},

$$SL = 10\log_{10}(P_{input}) + 10\log_{10}(\eta_{effic.}) + DI + 170.8$$
$$SL = 10\log_{10}(P_{input}) + C \qquad dB \tag{2}$$

where $\eta_{effic.}$ is the conversion efficiency, *DI* the directivity index, and 170.8 is a value based on the properties of the medium and the case of an omnidirectional source. The efficiency and directivity were not measured. The term *C* consolidates $\eta_{effic.}$, *DI*, and 170.8 since they are constants. Adjusting *C* in Equation 2 allows us to compare the data with theory, at least with regards to curve shape. The solid line in Figure 7 was produced with a value of *C*=202.5 dB, which gave excellent agreement.

A more objective approach is presented in Figure 8. The slope of Equation 2 on a dB vs $10 \cdot \log_{10}$ plot should be unity. In Figure 8 the linear least squares slope was determined to be within 7% of unity (the lowest-power data point was excluded in the fit). Figures 7 and 8 both suggest that the acoustic source has not reached acoustic saturation. In that case, the acoustic output would lie below the solid line in Figure 7 at high source levels.

4.3.2 Modulated Pulses

Figure 9 shows sound pressure level, *SPL*, versus range for modulation frequencies of 1, 2, 4, 8 and 10 kHz. The drive level was 751 mV for all data points (approximately 800 W rms input to ceramics). One can see that as the difference frequency increases so does the *SPL*. This effect is described in the literature [6, 7]. The peak in *SPL* in the vicinity of 4 to 6 m range was measured by taking a comparatively high density of data close to the projector. The location of this peak will be modelled using [8] and presented at a later date [9].

An alternate look at the range dependent data is shown in Figure 10, where the parametric gain is plotted versus range for all difference frequencies. The parametric gain, G (dB), is defined as,

$$G = SPL_d - SPL_p \quad (dB) \tag{3}$$

where SPL_d and SPL_p are the sound pressure levels of the difference and primary frequencies, respectively. Expression 3 is computed at the same point along the axis.

Shown in Figure 11 are the primary and secondary sound pressure levels for a difference frequency of 4 kHz versus increasing input power, measured at 5 m range. The parametric gain is plotted versus scaled primary source level [6], which is given by,

$$SL_p^* = SL_p + 20 \cdot \log_{10}(100\,kHz) \quad (dB//1\mu Pa \cdot m \cdot kHz) \tag{4}$$

for the case of a 100 kHz primary frequency. As in reference [6], the slope of this function should be unity for SL_p^* less than approximately 270 dB//1μPa-m-kHz. A linear fit to the data yields a slope of just less than unity, 0.83. This may be due to the measurement being taken within the Rayleigh distance, R_0, of the transducer defined as the ratio of transducer area to radiated wavelength, L^2/λ [10]. For PATS, this value was estimated as 7.9 m using L=34 cm, f= 100(10^3) and c=1460 m/s.

Figure 12 shows the parametric gain, G, obtained from the data in Figure 11. In the absorption limited regime of operation, the slope of this data is predicted to be unity [7]. The measured slope is 0.83, falling short of the mark. The reason is unclear at this time for the discrepancy, but may be due to the proximity to the projector. In Figure 13, the data of Figure 11 are plotted one versus the other, with the difference frequency plotted along the vertical axis and the primary frequency plotted along the horizontal axis. The slope of this data should be 2 in log-log space [11]. A linear fit to these data gives a slope of 1.83. This may, or may not, be due to measuring within the Rayleigh distance. The doubt in this statement is due to the fact that the on-axis pressure for a point source and the PATS equivalent circular piston only differ by less than 1 dB at 5 m range (see expressions 8.31b and 8.32 in reference [10] which suggests there should be little problem measuring at 5 m.

4.4 Waveform Harmonic Distortion

Figure 14 presents the harmonic distortion components of a 100 kHz sinewave modulated at 2 kHz for increasing signal power. As the input power increased, so too did the amplitude of the primaries (98 and 102 kHz). Moreover, what is most important is that the relative difference between the primaries and the harmonic components lessens. That is, as the medium is pushed harder and harder into service to sustain the transmitted waveform more energy is pumped into the distortion components. These are the effects predicted for finite-amplitude waves in a medium which is not linear, as is usually assumed.

5.0 COMPARISON TO THEORY

A detailed account of the theory is not presented in this report. A forthcoming paper will present a detailed comparison of the collected data to the theory [9]. Due to technical problems during the calibration, the amplifiers could not be made to drive the projector to its intended primary source levels, thereby creating a saturation-limited parametric array, as described in [6] and [7]. This meant that all data collected during this calibration are considered to place the parametric array in the absorption-limited regime. Parametric arrays operating in the absorption limited regime exhibit the general features of the data in Figures 7, 8, 11, 12 and 13 (i.e. regarding slopes and linearity). Nearfield modelling based on [8] and [12] will test the validity of the presented data.

6.0 CONCLUSION

PATS provides the transmit element in DREA's Wideband Sonar. The calibration of PATS (Parametric Array Transmit System), as designed and built by Guigne International Ltd., took place at the DREA Barge during January 25-29, 1999. The collected data underwent a subsequent preliminary analysis during February 1-5, 1999.

This report presented a description of the measurements, the software used to obtain and manipulate the data, and showed the preliminary results.

The data presented follows trends consistent with the theory of an absorption-limited parametric array. The beam patterns exhibit a very high directionality with an absence of sidelobes, and the slopes of several linear relations (in log-log space) reinforce the expected behaviour. Because a more detailed analysis could not be performed during the week of February 1st it would not be prudent to state at this time full compliance with the theory. A detailed comparison with theory, based on a numerical model, is to be carried out by the Scientific Authority, Dr. P Hines of DREA. The results of that work are forthcoming.

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Appendix A
Figures

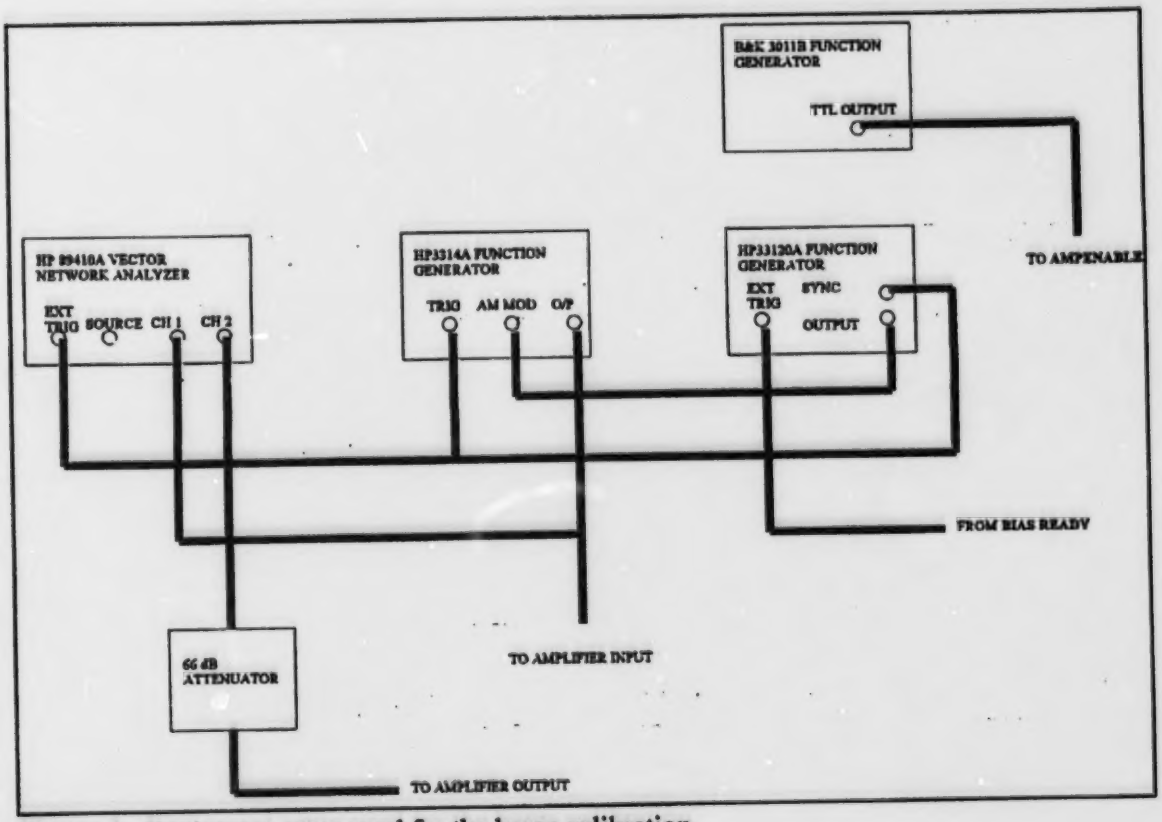

Figure 1. Equipment setup used for the barge calibration.

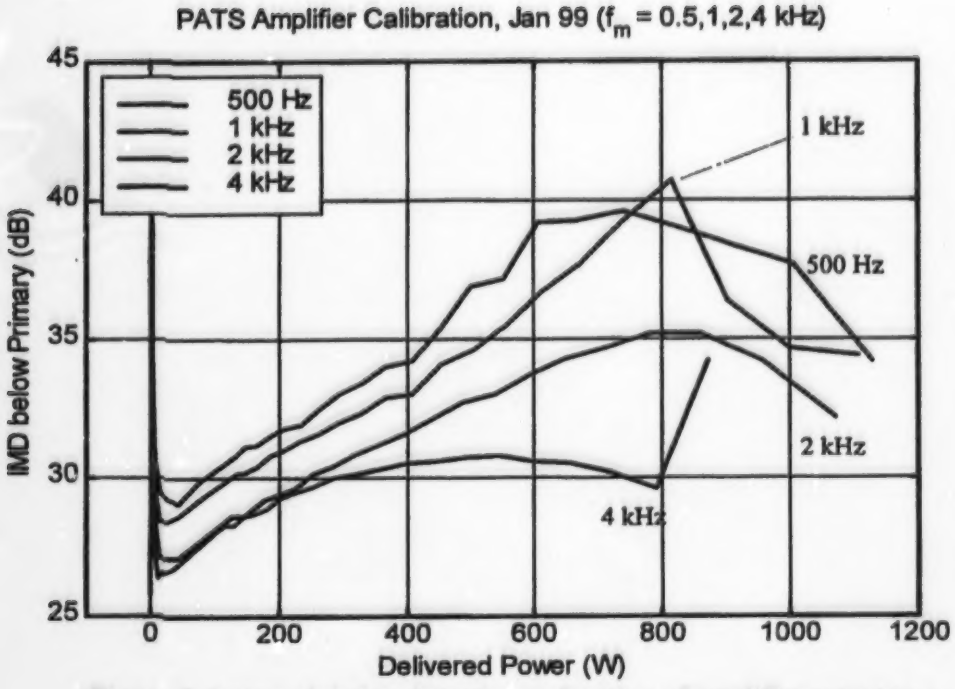

Figure 2. Intermodulation distortion as function of amplifier output to the transducer ceramics.

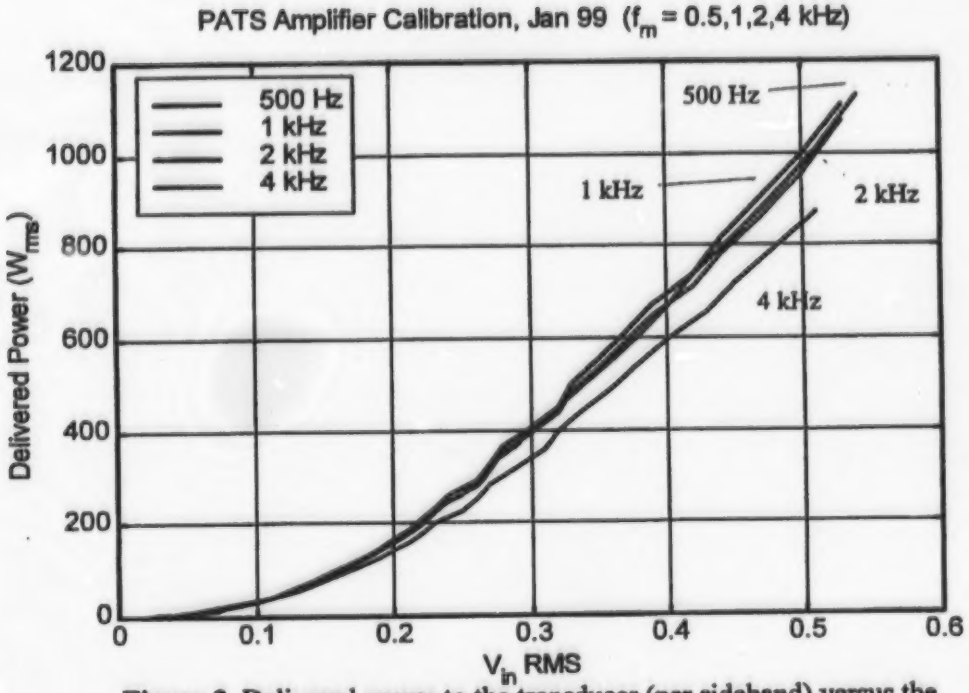

Figure 3. Delivered power to the transducer (per sideband) versus the input voltage to the amplifier network (complete PATS system).

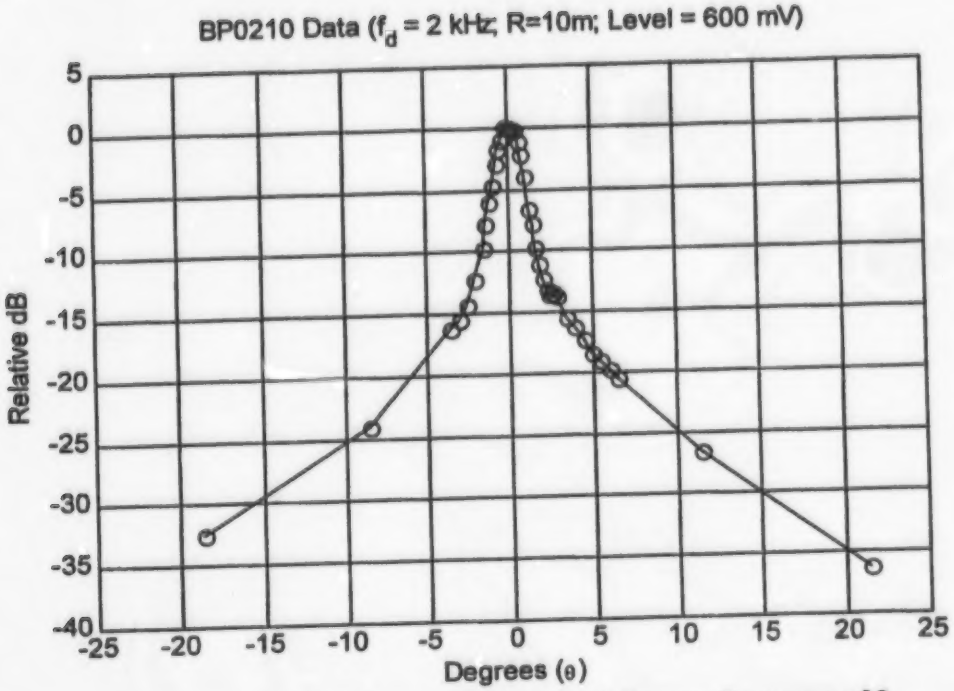

Figure 4. Secondary beam pattern at the difference frequency of 2 kHz and range of 10 m.

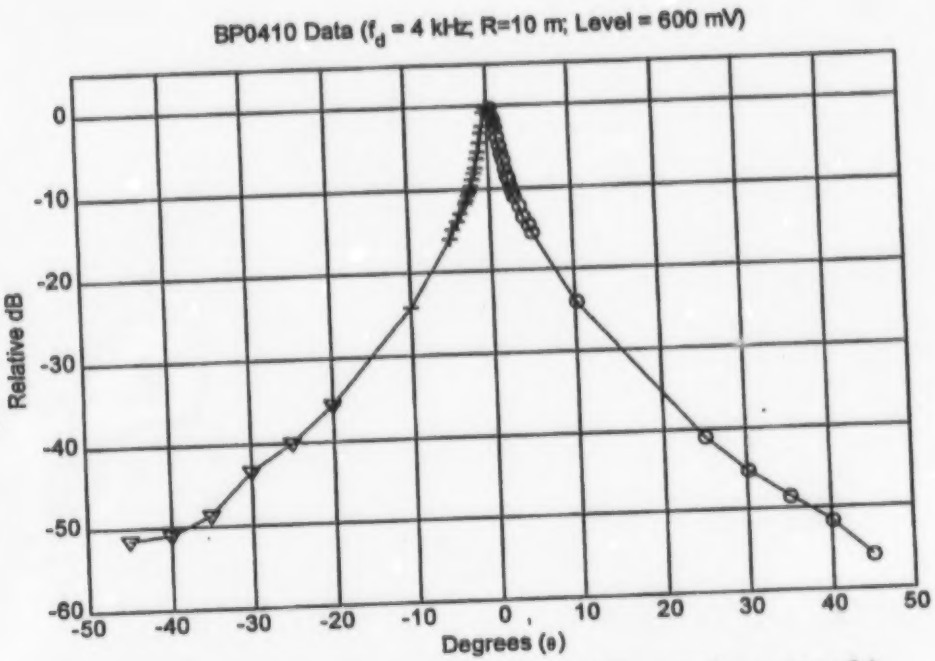

Figure 5. Secondary beam pattern at the difference frequency of 4 kHz and range of 10 m.

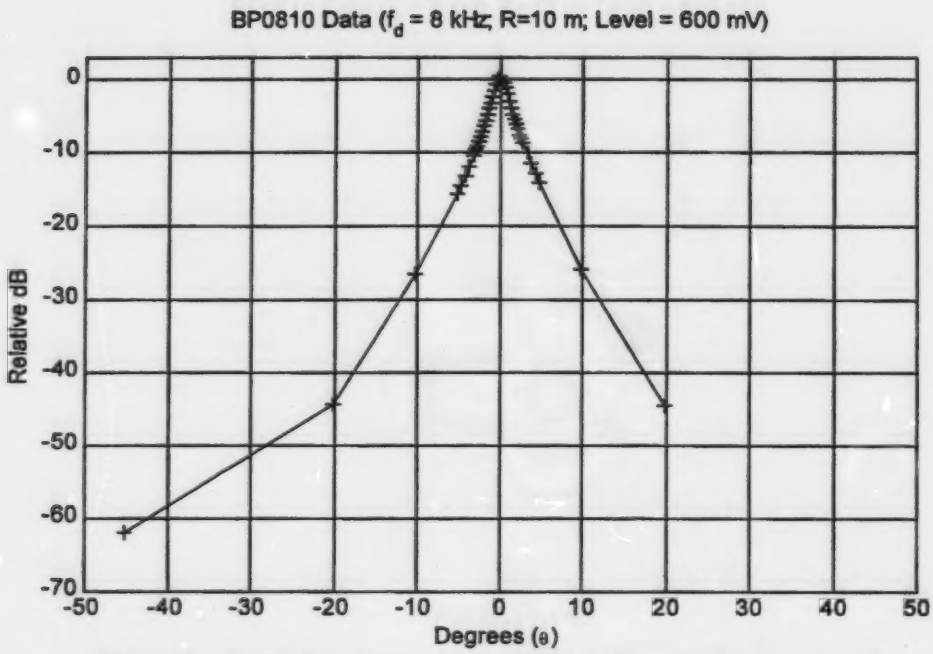

Figure 6. Secondary beam pattern at the difference frequency of 8 kHz and range of 10 m.

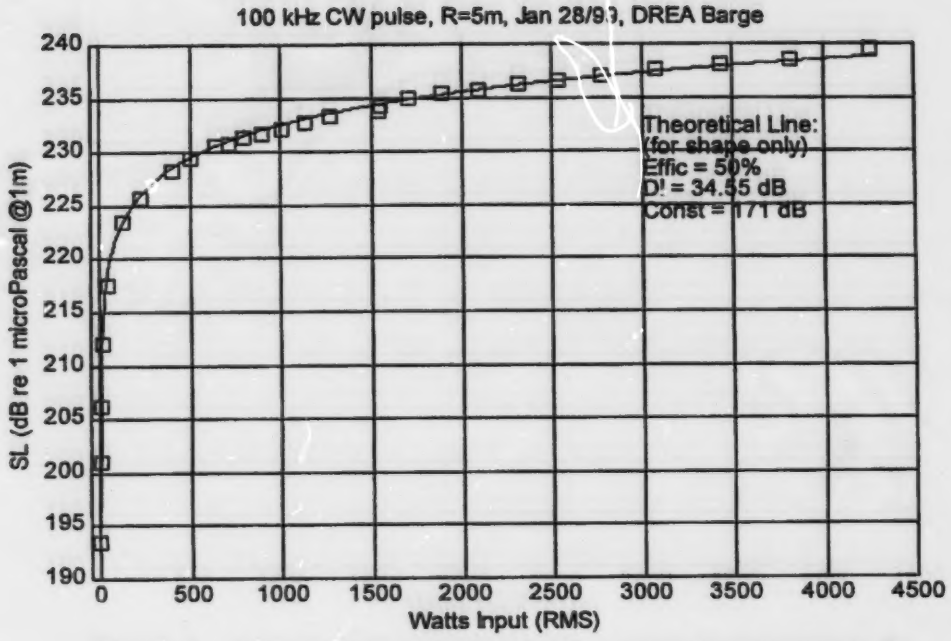

Figure 7. Acoustic output measured at 5 m versus input power to the ceramics.

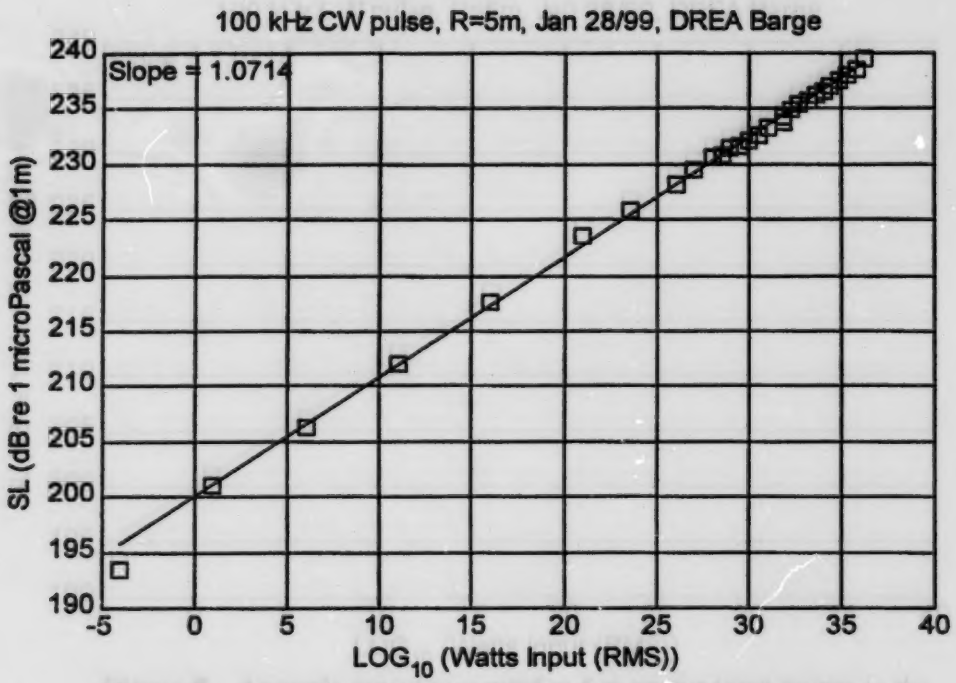

Figure 8. Acoustic output measured at 5 m versus input power to the ceramics.

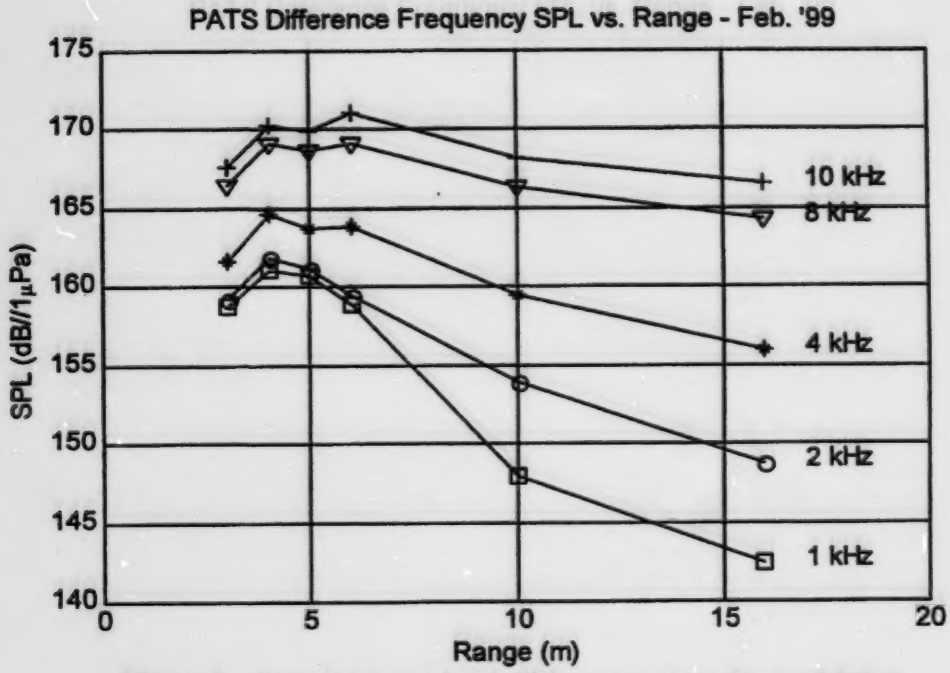

Figure 9. Sound pressure level, *SPL*, versus range for modulation frequencies of 1, 2, 4, 8 and 10 kHz.

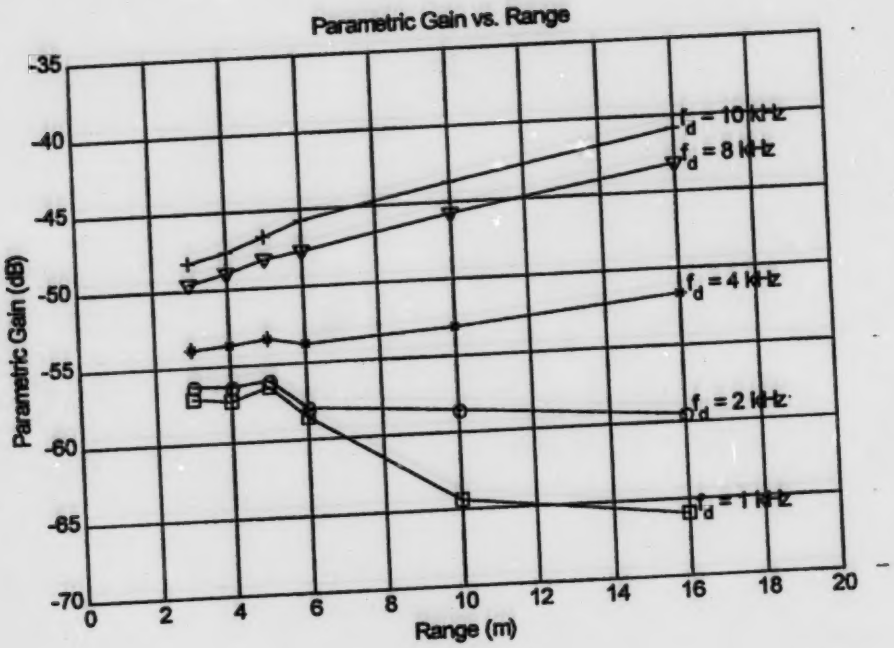

Figure 10. The parametric gain versus range for the difference frequencies of 1, 2, 4, 8 and 10 kHz.

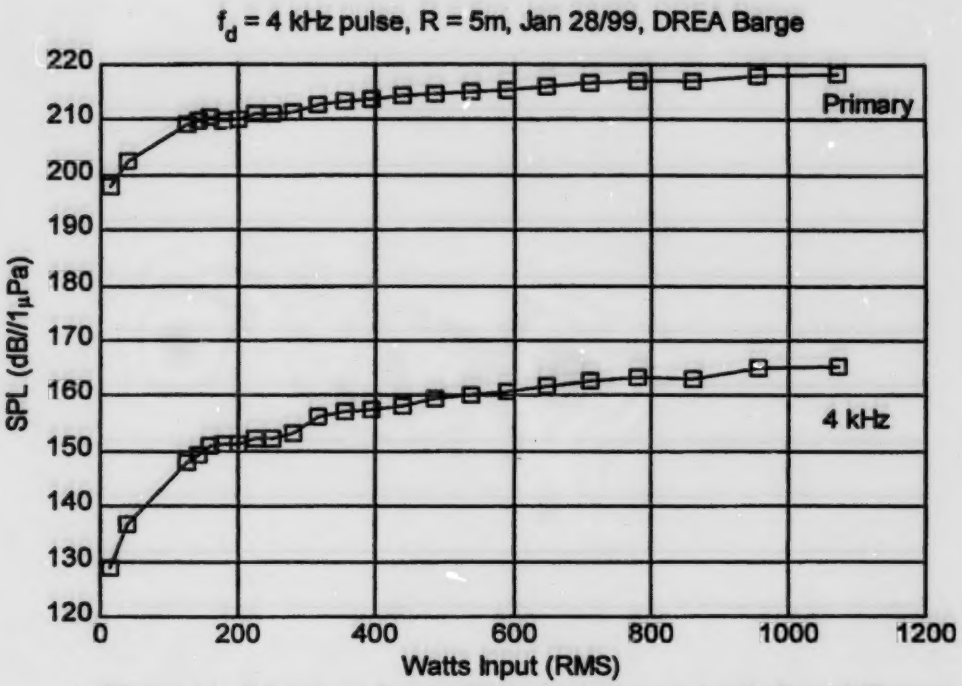

Figure 11. Primary and secondary sound pressure levels for a difference frequency of 4 kHz versus increasing input power, measured at 5 m range.

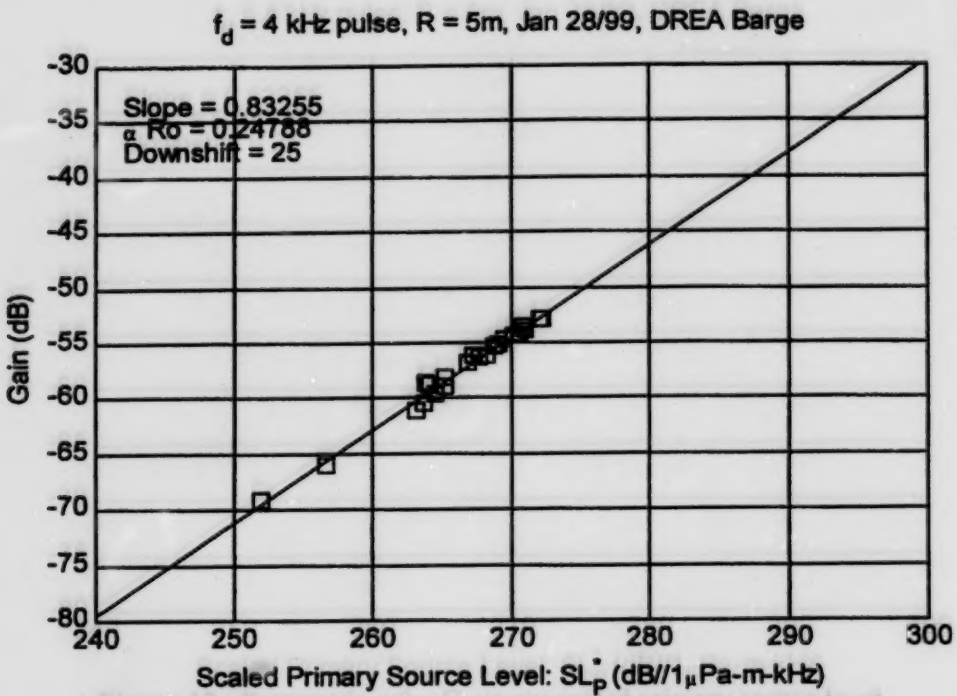

Figure 12. Parametric gain, G, versus scaled primary source level, SL_p^*. The measured slope is 0.83 as compared to the predicted slope of unity.

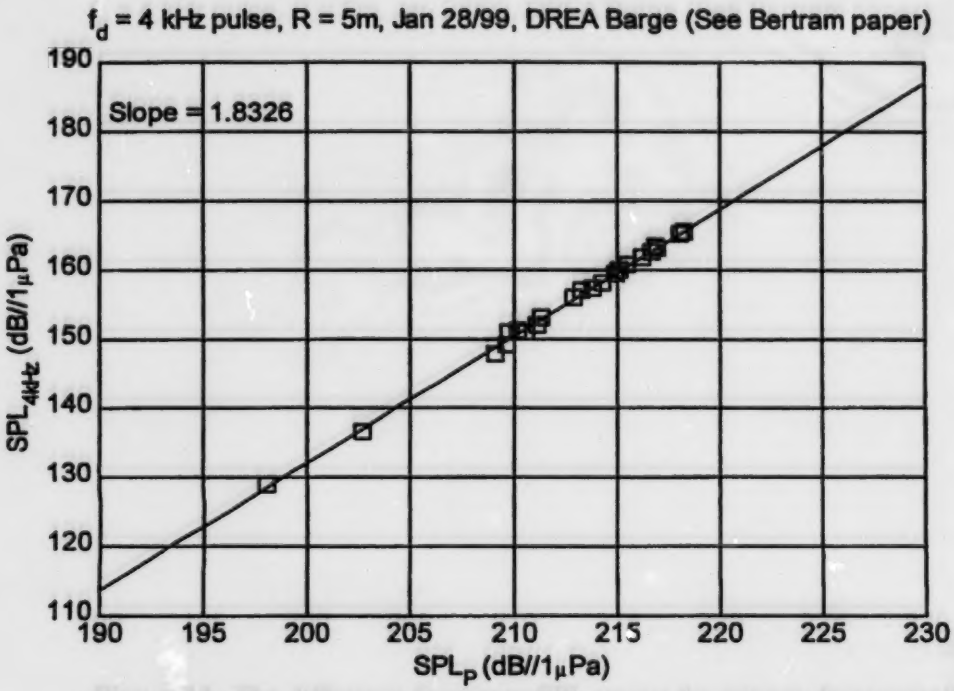

Figure 13. The difference frequency SPL versus the primary frequency SPL for f_d = 4 kHz at a range of 5 m. The measured slope is 1.83 as compared to the predicted slope of 2.

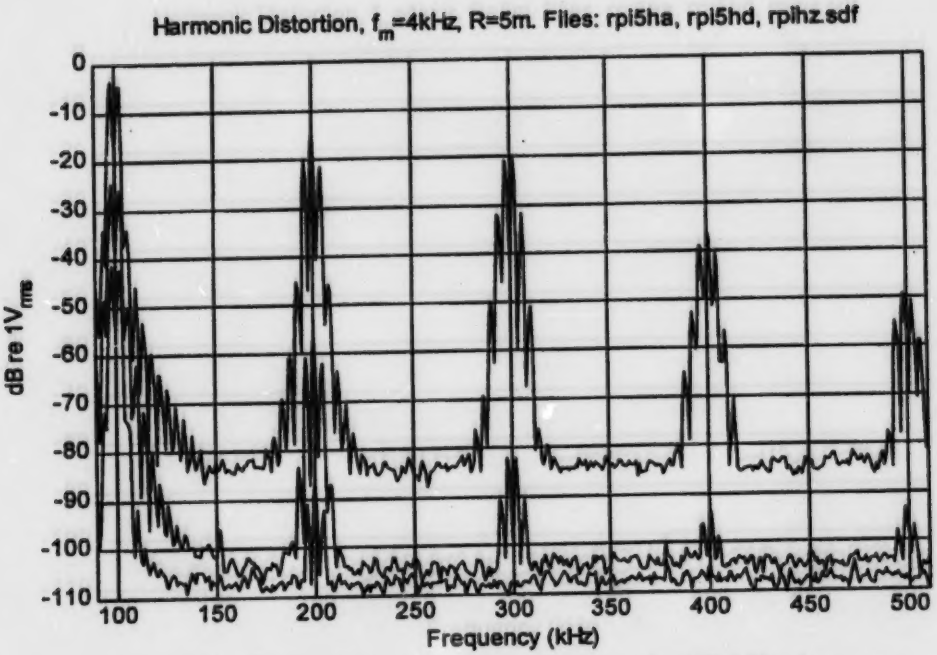

Figure 14. Harmonic distortion components of a 100 kHz sinewave modulated at 2 kHz for increasing signal power.

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Calibration of PATS at DREA Calibration Barge

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

C.A. Hamm

5. DATE OF PUBLICATION (month and year of publication of document)

30 April 1999

6a. NO .OF PAGES (total containing information Include Annexes, Appendices, etc).

17

6b. NO. OF REFS (total cited in document)

12

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered).

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8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include address).

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9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant).

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W7707-8-6319A

10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

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This report describes the calibration of the PATS sonar during January 1999 at the DREA Calibration Barge. The PATS sonar is a high-powered low-frequency parametric array designed and built by Guigné International Ltd., Paradise, Newfoundland. Tests were carried out at the primary frequency of 100 kHz and difference frequencies 1, 2, 4, 8 and 10 kHz. Measurements were carried out at ranges between 3 m and 16 m from the transducer face along the acoustic axis. At a range of 10 m beam pattern measurements at difference frequencies 2, 4 and 8 kHz were made. Measurements in both the time and frequency domain, over the frequency range 90 to 510 kHz, were made which illustrate the harmonic distortion brought on by finite amplitude propagation of a 100 kHz CW signal. This report describes the experimental setup, methodology, data format, data organization, and graphically presents a portion of the data collected. A comprehensive theoretical evaluation of the data was not performed. This work was carried out with the assistance of the Scientific Authority, and DREA technical staff, and was supported by DSS Contract W7707-8-6319/A.

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